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Multi-Disciplinary Hands-On Desktop Learning Modules and Modern Pedagogies

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AC 2012-5271: MULTI-DISCIPLINARY HANDS-ON DESKTOP LEARNING MODULES AND MODERN PEDAGOGIES

Prof. Bernard J. Van Wie, Washington State University

Prof. Van Wie has been teaching for 29 years, first as a graduate student at the University of Oklahoma and then as a Professor at Washington State University. Over the past 14 years he has devoted himself to developing novel teaching approaches that include components of Cooperative/Collaborative, Hands-on, Active, and Problem/Project-based Learning (CHAPL) environments.

David B. Thiessen, Washington State University

Dr. Marc Compere, Embry-Riddle Aeronautical Univ., Daytona Beach FL

Dr. Compere's research in renewable and sustainable technology includes water purification for disaster relief and concentrated solar power for electricity generation, water desalination, and engineering education. He leads a yearly effort named Project Haiti to design, build, and install a solar powered water purifier in Haiti with students on an annual basis. He teaches senior design, vehicle dynamics, and instrumentation courses. In addition to Clean Energy his research pursuits include hybrid electric vehicles, hardware-in-the-loop modeling, simulation and control, and swarm robotics with multiple heterogeneous unmanned air and ground vehicles.

Ms. Ximena Toro

Ms. Ximena Toro graduated with a Master's of Science in Mechanical Engineering in the Fall of 2011 and graduated with Bachelors of Science in Engineering Physics from Embry-Riddle Aeronautical University in 2010. She is interested in Clean Energy Systems and has native fluency in English and Spanish. She is currently working at General Motors as a Development Engineer for the Chevrolet Volt and has worked for Mitsubishi Power Systems as a Mechanical Engineer.

Dr. Jennifer C Adam, Washington State University

Dr. Jennifer Adam is an Assistant Professor in the Department of Civil and Environmental Engineering at Washington State University (WSU). She applies numerical hydrologic models to investigate the impacts of climate change on regional to continental scale hydrology. For example, she and collaborators are currently integrating a regional-scale hydrologic model with a crop growth model to explore how projected climate change will impact water resources availability for irrigation and crop yield under various socio-economic scenarios. She teaches 3 courses: (1) a required undergraduate-level course in Water Resources Engineering in which she is researching the use of hands-on inquiry-based learning in the classroom; (2) a senior elective course in Sustainable Development in Water Resources, which explores the concepts needed to understand how to more sustainably manage our limited water resources in the western US under increasing pressures, particularly climate change; (3) and a graduate-level course in Hydroclimatology, which is a primarily student-led course that immerses the student in the academic literature surrounding the relationships between climate and hydrologic processes, and how these relationships impact the various sectors of society, including agricultural production. Dr. Adam is a recent recipient of outstanding teaching awards at both the WSU departmental and collegiate levels.

Dr. Shane A. Brown P.E., Washington State University

Dr. Brown conducts research in conceptual and epistemological change, social capital, and diffusion of innovations. In 2011 he received the NSF CAREER Award to investigate how engineers think about and use concepts that academics consider to be important.

Mr. Andrew P Easley, Washington State University

Andrew Easley is a graduate student at Washington State University in the Civil and Environmental Engineering Department. He received his Bachelor's Degree from the Washington State University. His current research topic is to investigate the effectiveness of Desktop Learning Modules that model fundamental open channel flow concepts.

Ms. Xuesong Li P.E., Washington State University

Xuesong Li is a graduate student at Washington State University in the Chemical Engineering Department. She got her Bachelor's Degree from Shenyang University of Chemical Technology in China. Her current research focuses on biomedical engineering applications in biosensors which is called Dual Ionophore Ion-Selective Electrode (di-ISE) biosensor.

Mr. Kevin Lee, University of Idaho

In cooperation with Bernie Van Wie at Washington State University, my project research focuses on cell sensor and biological sample reading principles. This biomedical engineering cartridge is designed for detecting and determining concentration of biological cells in suspension at a specific wavelength.

Mr. Mert Colpan, Washington State University

Mert Colpan is a graduate student at Washington State University and he is seeking a PhD Degree in Bioengineering. He got a dual Bachelor's Degree in Bioengineering from Istanbul Technical University and Montana State University. His research subject is to investigate the factors regulating function of tropomodulin, an actin-capping protein.

Mr. Kevin Tyler Gray, Washington State University

Kevin Gray is a graduate student at Washington State University in the Chemical Engineering Department. He got his Bachelor's Degree from the Georgia Institute of Technology. His current research topic is to investigate the role of Tropomodulin 2 in actin filament dynamics and its implications for neurite out growth.

Mr. Benjamin Garrett, Washington State University

A senior chemical engineering student at Washington State University who worked with a group of students to gather heat transfer coefficient data for the extended area heat exchanger DLM cartridge.

Shane Riley Reynolds, Washington State University

Mr. Shane Reynolds is currently an undergraduate and will be graduating with a Bachelors of Science in Chemical Engineering in 2012. He helped develop the latest models of the Desktop Learning Modules and he will be working for E & J Gallo Winery as a process engineer after graduation.

Dr. Paul B Golter, Washington State University

Paul Golter has been the Instructional Laboratory Supervisor for Washington State University's Chemical Engineering and Bioengineering Department for the last 10 years. He has also been a part time graduate student at this time and recently completed his Ph.D. in Engineering Science working on the development and assessment of a novel pedagogy and a set of equipment that allows simple fluid mechanics and heat transfer experiments to be performed in standard college classrooms.

Dr. Olusola Adesope, Washington State University-Pullman

Olusola O. Adesope is an Assistant Professor of Educational Psychology at Washington State University, Pullman. His research is at the intersection of educational psychology, learning sciences, and instructional design and technology. His recent research focuses on the cognitive and pedagogical underpinnings of learning with computer-based multimedia resources; knowledge representation through interactive concept maps; meta-analysis of empirical research, and investigation of instructional principles and assessments for engineering designs.

Multi-Disciplinary Hands-on Desktop Learning Modules and Modern Pedagogies

Abstract

Our team's research focuses on fundamental problems in undergraduate education in terms of how to expand use of well researched, yet still "new", teaching pedagogies of 'sensing' or 'hands-on', 'active' and 'problem-based learning' within engineering courses. It is now widely accepted that traditional lectures ARE NOT best for students – yet that is what the community almost universally does.

To address this issue we are developing new Desktop Learning Modules (DLMs) that contain miniaturized processes with a uniquely expandable electronic system to contend with known sensor systems/removable cartridges, as well as, unknown expansions to the project. We have shown that miniaturized mimics of industrial-scale equipment produce process data that agree with correlations developed for large-scale equipment. We are now adapting concepts shown efficacious in a single chemical engineering course to a variety of engineering classes within civil, mechanical, bio- and electrical engineering. Some examples of new hands-on learning applications in chemical engineering include a boiler / condenser and evaporative and shell & tube heat exchangers. In bioengineering, we are developing prognostic devices for separating Prostate Cancer Tumor Cells (PCTCs) from blood, sensing for the presence of PCTCs, a thermoregulation simulated limb cartridge for studying kinematics of heat flow and heat distribution in human extremities, and immunoaffinity neuron-like ion selective electrodes. In civil engineering, the DLMs illustrate open channel flow units and a solar powered Rankine cycle is underway in mechanical engineering. We are implementing DLMs along with team learning pedagogy.

In this paper we will present technical aspects surrounding development of a large number of new learning cartridges. While the assessment strategies being developed are broadly applicable we will just present one instance, with the civil engineering cartridge, of the identification of misconceptions and experimental design for assessing the impact of the DLM on learning. The assessment includes a pre- and post-test assessment to determine improvement in understanding basic concepts and persistence and/or repair of misconceptions.

Introduction

Hands on teaching methods have a long history of use in science and engineering. Usually this is seen in the form of laboratory classes that either accompany a lecture course to reinforce concepts and teach research skills; or capstone laboratory courses which occur toward the end of an undergraduate curriculum. In general laboratory courses the aim is to bring the students into some variety of a learning cycle, such as Kolb's experiential learning cycle [1, 2], shown in Fig. 1. This entails: Concrete Experience (CE) or a look at what is happening here and now as module process variables are manipulated, Reflective

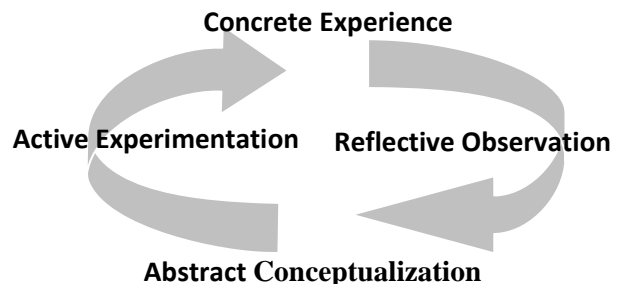


Fig. 1. Common Kolb's learning cycle.

experiential learning cycle [1, 2], shown in Fig. 1. This entails: Concrete Experience (CE) or a look at what is happening here and now as module process variables are manipulated, Reflective

Observation (RO) or what is the meaning of what was just observed, Abstract Conceptualization (AC) or how can these observations be quantified mathematically, and Active Experimentation (AE) or how can process variables be adjusted, mathematical formulas reduced and new information added to complete understanding of important concepts?

Some work is underway to bring hands-on experiences into courses where they are usually absent [3, 4]. Such attempts generally involve low cost, easy to obtain materials. For example, an ice cream maker is used to teach process engineering [5]; in another instance students examine what happens when pop goes flat [6]; others employ a stir-plate and ice bath to study kinetics, heat transfer and sensor dynamics [7]; a mug warmer and CPU cooling devices are used for studying heat transfer [8]; and a cup of coffee to teach transport phenomena [9].

What has been lacking are ways to bring the type of equipment usually reserved for a capstone laboratory class into classrooms earlier in the curricula. Some attempts at doing this include projects where the students themselves build miniature desktop or table-top learning systems. An early example within the chemical engineering discipline includes a class taught by co-author Van Wie where student teams made an extended area heat exchanger, a coin separator, an ice cream maker and several other systems [10], with more recent implementations of classroom DEMos reported by Minerick [8, 11] and by Visco [12]. Drawbacks here are that each student team tends to focus mainly on their own system, such that other teams benefit minimally from what another team learns, and it can take a number of iterations through several years by different student teams to update and perfect a system so that it can operate reliably. To compensate for these drawbacks Golter et al. [13, 14] developed a set of hands-on classroom systems consisting of small heat exchangers and fluids systems, rack-mounted with small white boards for modeling equations. The concept was later updated in the form of Desktop Learning Modules or DLMs which contain a one cubic foot base system with hot and cold fluid reservoirs, flow meters, temperature and pressure readouts and a set of interchangeable unit operations cartridges [15, 16].

Recent efforts extend the DLM concept to the civil engineering discipline [17]; now a more concerted effort and rigorous study is taking place in Civil Engineering with expansion to Bio-, Mechanical and Electrical Engineering underway [18]. In this paper, we highlight some of the new interchangeable cartridges that are being developed and their utility in terms of concepts and principles that can be learned or reinforced by those using them. We also highlight a pre- / post-test strategy being piloted in the civil engineering implementation, which will have general applicability and adaptability to other disciplines for assessing the impact of DLM usage in resolving misconceptions that typically persist even after students complete a lecture-based format classroom experience. Included is a detailed summary that identifies the Civil Engineering misconceptions that serves as an example of what we expect to do in parallel in other disciplines.

Bioengineering Cartridges

Neurophysiology and Immunosensor Concept

Our first emphasis regarding biomedical engineering applications involves learning about neuronal membranes in biomedical engineering classes with a miniature hand-held rapid-format dual

ionophore ion selective electrode (di-ISE) measurement system [19]. The concept can also be extended to sensing of proteins and complex organic species for learning about novel applications of neuronal membrane concepts as will be described here. ISEs have been developed for ion sensing purposes for more than thirty years [20] and are useful for a wide variety of applications in pollution control [21], water quality monitoring[22], waste water treatment, food quality control [23], medical diagnosis and hygiene [24], the pharmaceutical and cosmetics industry [25], industrial production [26], and education [27]. Our di-ISE is inspired by living neuronal physiology and illustrated in Fig. 2 with a sensing application to the model analyte cardiac Troponin I (cTnI). The di-ISE will consist of a hapten-ionophore conjugate (HIC) linked to a K^+ ionophore, and antibody to the hapten, and an ionophore to a second ion, in this case Na^+ . When opposing concentrations gradients of K^+ and Na^+ are present the system starts at a resting voltage that corresponds to the relative permeability of each ion species and species concentration gradients. When an antibody to the HIC binds, this complex will be sequestered on one side of the membrane, hindering the flow of K^+ ions (A). Immuno-competition can then occur when antigen is present in solution releasing the antibody and allowing free transport of K^+ ion to the other side (B); this results in voltage modulation.

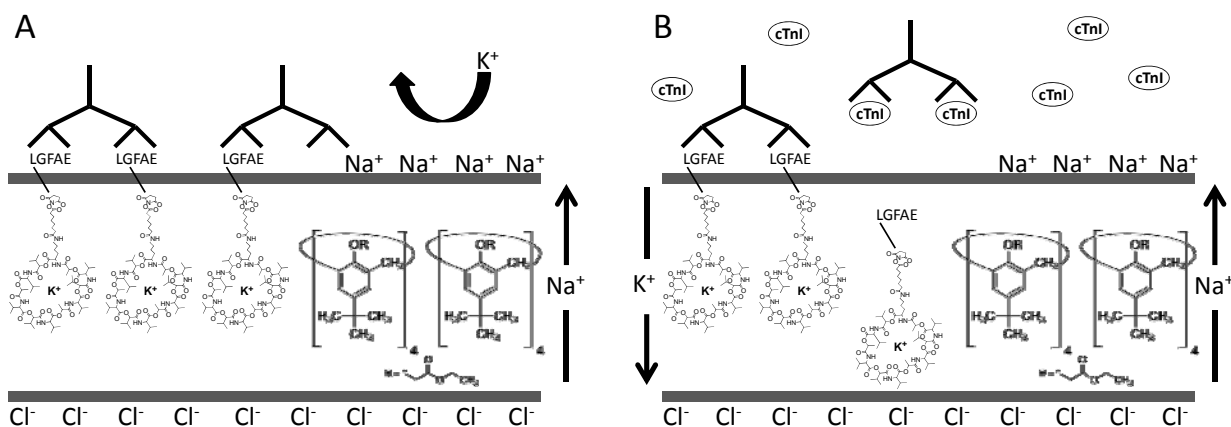


Fig. 2. Dual ionophore ion selective membrane for model analyte cardiac Troponin I (cTnI).

In a miniature hand-held model neuron-like system we constructed a di-ISE membrane with valinomycin, a highly selective K^+ ionophore (A.G. Scientific. Inc., San Diego, CA) and 0.1% NaX (Fluka, SL Louis, MO). To simulate voltage changes that occur when K^+ permeabilities are changed we vary the amount of valinomycin in the membrane from 0.001 to 3 wt%. Preliminary data for a 1 M external K^+ concentration and 0.1 M internal Na^+ concentration are shown in Fig. 3 with di-ISE voltage responses as a function of model analyte concentration in solution. We see a base value of about 40 mV for 0.001% valinomycin concentration or a simulated analyte concentration of 10^{-7} M cTnI, assuming a 1:1 ratio of HIC bound antibody and antibody competed away by cTnI in solution. cTnI concentrations are based on the amount of HIC in a 30 μ m sized ISE made from 1 μ L volume of membrane cocktail and placed in 0.7 μ L of sample. There is a steady increase in voltage to 250 mV for 3% valinomycin concentration or a model analyte concentration of nearly 10^{-3} M cTnI.

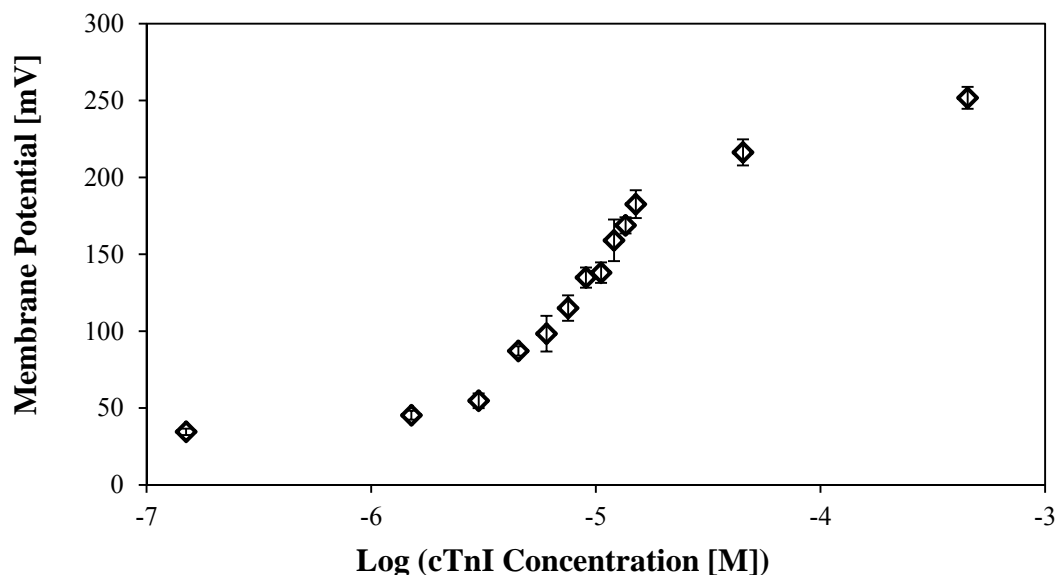


Fig. 3. Data simulating cTnI sensing in a di-ISE based on changing valinomycin concentration within a 30 μm diameter 100 nm thick membrane containing 0.1% NaX.

Cell Sensor and Biological Sample Reading Principles

A new miniature desktop cell sensor cartridge, shown in Fig. 4, is designed for detecting and determining concentrations of biological cells in suspension. Initial tests are focusing on monitoring prostate cancer tumor cells (PCTCs) in simulated circulating human blood.

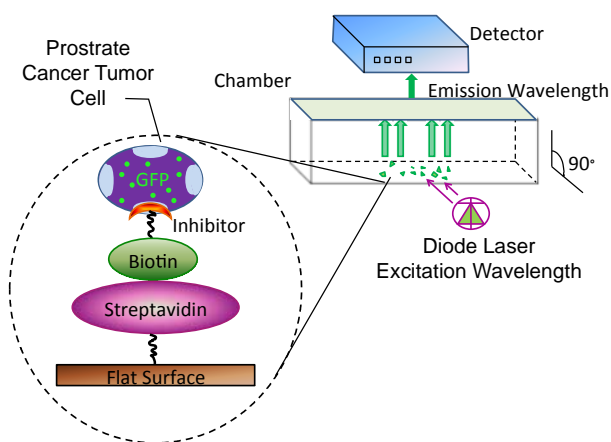


Fig. 4a. Schematic of the biosensor.

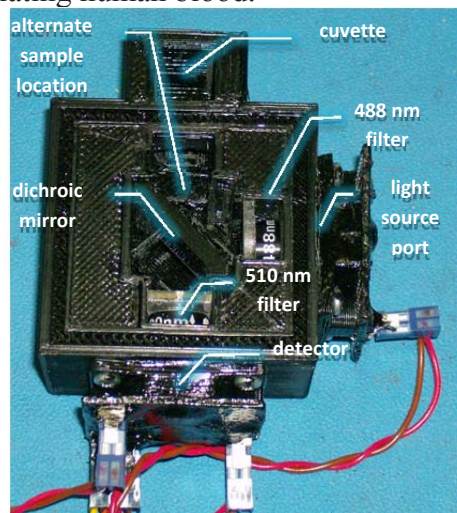


Fig. 4b. Infinitix chamber.

The final design will include two pistons that dispense the labeled inhibitor and cell suspensions. A small volume of cell suspension flows through the cuvette, coated with streptavidin that binds to a biotin-inhibitor complex where the inhibitor binds specifically to an enzyme known as prostate specific membrane antigen or PSMA.

Our first cell suspension will consist of GFP-LNCaPs, which are prostate tumor cells transfected with green fluorescent protein. A prototype cartridge has been designed and tested by our collaborators at Infinitix Corporation (Spokane, WA) and is shown in Fig. 4b. When cells pass through the cuvette they are captured by the enzyme inhibitor and the numbers captured related to the GFP-LNCaP concentration. Excitation light at 480 nm leads to GFP fluorescence read at 90° through a 515 nm filter. For detecting non-fluorescent LNCaPs, cells are captured, the cuvette purged of remaining cells, FITC-labeled inhibitor added, the system washed of non-captured FITC-labeled inhibitor, and final fluorescence read as before.

Preliminary results were collected to confirm that biotin-FITC could be bound to streptavidin coated 96-well plates. Data plotted on a fluorescence vs. log of concentration graph show the typical S-shaped curve for adsorbed species with a minimum detection limit of 50 μ M and maximum value of 5 mM of Biotin-FITC. The next experiment was to determine if the biotin-inhibitor could capture the DAPI-LNCaPs on the coated plastic surfaces. DAPI or 4',6-diamidino-2-phenylindole is a fluorescent stain that binds strongly to A-T rich regions in DNA that excites at 358 nm and emits at 461 nm. Preliminary results suggest when more PCTCs are in suspension there is indeed a higher fluorescence intensity than less concentrated suspensions and both high and low suspension concentrations result in higher fluorescence than what occurs with non-specific binding in non-biotin-inhibitor-coated plates. The experiment was done on a 96-well plate in triplicate and the averages taken. The plates were pre-blocked with Bovine Serum Albumin (BSA). We experimented with 5 times more and 5 times fewer cells from a 50,000 cell stock. The plate was incubated with biotin-inhibitor overnight at 4°C. Cells were added to wells; controls contained cells without inhibitor. The plate was incubated on a shaker for 1 hr at 4°C. After that, we fixed the cells with 3% DAPI and 2% formaldehyde in a phosphate free medium. Table 1 shows results from triplicate runs from an experiment with DAPI-LNCaPs. Wells containing 250,000 cells give a fluorescence ratio of 2.4 when compared to control wells not coated with biotin-inhibitor while those with only 5,000 cells have a ratio of only 1.03. The ratio near 1.00 is probably because of non-specific binding or because not all cells were thoroughly removed in washing steps in the control experiment. The higher ratio with higher cell concentrations suggests that capture of cells to the plastic-bound inhibitor indeed occurs.

Table 1. Results from cell sensor simulation in a biotin-inhibitor coated 96-well plate.

No.	Experiment & Labeling	Fluorescence	Ratio (%)	Expt/Ctrl
0	Negative control or blank (only DAPI)	0		
1	5k cells + biotin-inhibitor	-563	#1/#3 = 44.5	1.03
2	Control (5k cells + medium)	-548	#2/#3 = 43.3	
3	Positive control (DAPI + 5k cells)	-1270		
4	250k cells + biotin-inhibitor	3580	#4/#6 = 59.6	2.40
5	Control (250k cells + medium)	1490	#5/#6 = 24.8	
6	Positive control (DAPI + 250k cells)	6000		

Preliminary measurements with a flow cell system, manufactured by Infinitix, indicate that FITC concentrations at the same levels as those used in the 96-well plate experiments show the prototype system can indeed detect FITC presence. The circuit outputs range from 0.0 to 3.0 volts and requires 60 mA of current, which may easily be read with our new prototype DLM system.

The sensor cartridge system can be used to supplement lectures on topics related to: 1) on-line detection of PCTCs in a system that simulates an ex-vivo flow cell that takes in circulating peripheral blood; 2) helping students understand sensing constructs that depend on excitation and emission light; and 3) application to detection of other cell types such as coliforms for monitoring water quality.

Cell Separations

Circulating Tumor Cells (CTCs) are an elusive cell type found in the blood of late stage cancer patients [28]. Currently researchers are seeking ways to collect CTCs in early stages of the disease to arrest cancer in pre-metastatic patients, and a biomarker for disease state and prognosis. For example, CTCs are correlated with disease state and disease free survival in Ovarian Cancer [29]. The leading challenge with detecting CTCs in blood is their scarcity, as low as 1 CTC/mL of whole blood [30]. One approach to collecting CTCs is to use a two-step separation process first using apheresis, then elutriation. A proof of concept study has shown that high purity can be achieved from elutriation of spiked leukapheresis of healthy patients [31].

In our labs various factors that impact apheresis are being investigated to improve separation in this initial step. Discussed here is the predicted impact of Hematocrit (HCT or cell fraction) on separation of circulating prostate cancer tumor cells (PCTCs) from Red Blood Cells (RBCs). This was motivated by previous work which shows White Blood Cells (WBCs) separate from RBCs quickest at lower HCTs [32]. Modifying the model developed previously [35], by using the diameter of the PCTC and compensating for the PCTC volume produces the results shown in Fig. 5. Included in the figure is the settling velocity difference for WBCs for comparison.

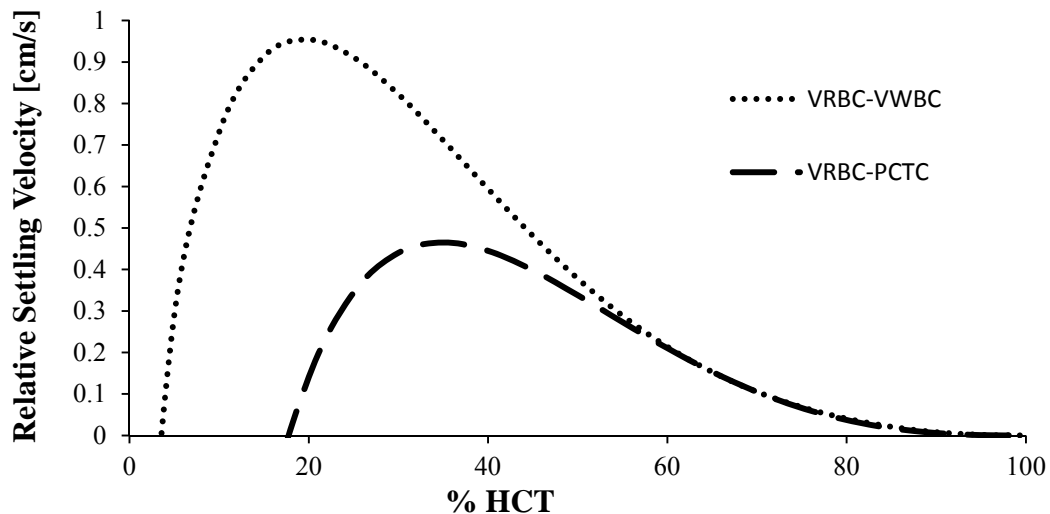


Fig. 5. The differences in settling velocities for both White Blood Cells (WBC) and Prostate Cancer Tumor Cells (PCTCs) from Red Blood Cells (RBCs).

This model predicts that the quickest separation of CTCs will occur at approximately 35% HCT; this predicts that separation is optimized at HCTs near to those of whole blood. To validate this claim, some preliminary data were collected. Samples of pig blood were spiked with prostate

tumor cells then diluted or concentrated to varied HCTs. The samples were then centrifuged and analyzed using a flow cytometer. Although the data will need to be verified with higher sample sizes and supporting assays, preliminary findings suggest that the best separation does occur near whole blood feed HCTs.

While the technical goal is a CTC sensor for patient blood and rapid and efficient purification of these cells, the learning goal in a DLM will be on understanding separations that result through sedimentation. We envision a rapid hands-on separation in inclined test tubes and assessment of CTC presence in cell isolates through numbering them in counting chambers under a microscope brought to the classroom.

Thermoregulation in a Simulated Limb

Heat transfer is a subject of significance to engineering students. Although universities offer extensive courses for providing an adequate understanding of heat transfer, incorporating theoretical knowledge to real-life applications may sometimes be challenging. Heat transfer processes occur in a variety of occasions in life such as thermoregulation in the human body. Therefore, utilization of a simple model to demonstrate this in class with a DLM could enhance the understanding of the subject. We have designed a simulated limb cartridge that mimics some aspects of heat transfer in the extremities. We ran a 3D heat-transfer model, using COMSOL Multiphysics software, for one subunit of the artery / vein fractal geometry. The subunit consists of four layers where a u-tube-shaped rectangular duct is embedded inside the three lower layers (Fig. 6). The rectangular layers were drawn to represent skin layers where the upper layer is the outermost and has contact with the exterior environment, which is air. On the other hand, the embedded rectangular duct was drawn to illustrate a capillary system where blood flows in and comes out to distribute heat to warm up the extremities via convection and conduction in biological tissue (skin layers). To represent blood and biological tissue, water and PMMA were selected as materials for the DLM respectively. PMMA is a derivative of glass and it will enable the observers to see the interior in a DLM model, where flow occurs. Additionally, PMMA is not a reactive material and its structure will not be affected by a temperature difference.

We ran a model in COMSOL assuming water flows in the duct with a volumetric flow rate of 0.1 gal/hr and it is at body temperature (310 K), where the PMMA layers and outer environment (air) is at room temperature (293 K). Unsteady-state solution of the model shows exponential decay to steady state to the outer surface temperature for the top PMMA layer (Fig. 7). Additionally, the temperatures of the outer layers converge to a steady-state temperature 309 K, which is very close to body temperature, in approximately 7 min. As a result, it we conclude that the DLM is capable of demonstrating the heat transfer and temperature change in different materials *via* convection and conduction in a relatively short period. The time needed for this demonstra-

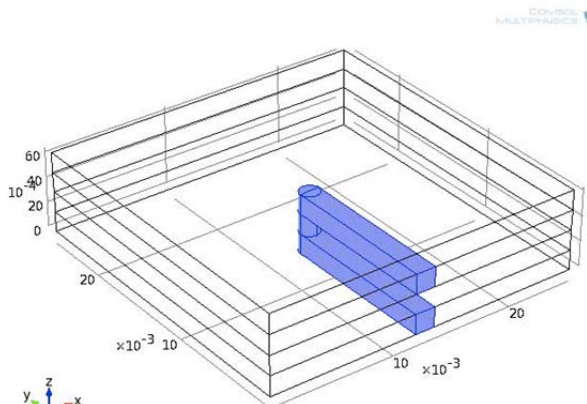


Fig. 6. The 3D model for the smallest section of a simulated limb cartridge. The four rectangular layers represent biological tissue and the embedded u-tube shaped channel represents an artery / vein system. The blue-colored domain represents the fluid.

tion is crucial because it will be shown to students in a regular class period, which is usually 50 to 75 min. Since 7 min is only a small fraction of this time a DLM cartridge based on the model is expected to enhance students' understanding of the topic and lessen the time they will spend in learning the subject. In conclusion, a simulated limb cartridge is a reasonable option for teaching heat transfer to engineering students through a hands-on learning experience.

Civil Engineering Flume, Misconceptions, and Assessment Strategy

Our Civil Engineering team is working on a DLM open channel flow component for water resources engineering. The DLM design was modified from its original configuration to better fit the needs of how to model open channel flow concepts in the classroom. The newest DLM (Fig. 8) is a more compact, simplistic device that can be used easily in the classroom. The DLM consists of a flume and a reservoir to house the water. There is a gate valve to control flow, a digital level to adjust slope, and a leveling platform. We have also included a digital flow meter device to monitor flow rate. The DLM operates on a small, rechargeable battery pack and a pump.

For identifying misconceptions preliminary results were collected in spring and fall 2011 in the form of 50 open-ended interviews with individual students and 41 pre/post-tests, respectively. Data suggest junior level students are developing robust misconceptions related to fundamental concepts. Concepts tested include: hydraulic jumps; flow profiles; flow transitions; hydraulic and energy grade line (HGL/EGL); and the most efficient section. The following is a brief summary of the findings.

Hydraulic Jump

A hydraulic jump occurs when flow transitions from a fast and shallow movement to a slow and deep movement. Inertial forces decrease due to friction and energy is dissipated as gravitational forces dominate as the fluid slows. Most tested students knew what a hydraulic jump looked like, but only one mentioned it was a transition from inertial to gravitational forces. Many students referenced the effects of a hydraulic jump such as the depth increases or the velocity slows, but these are indirect results of a hydraulic jump.

Flow Profiles

Students were given a few different flow profiles that ranged from passage through a sluice gate to a sharp crested weir. A global result is that the tested students hold incorrect beliefs relating to how water flows from one point to another. A great example of this is the result from the broad

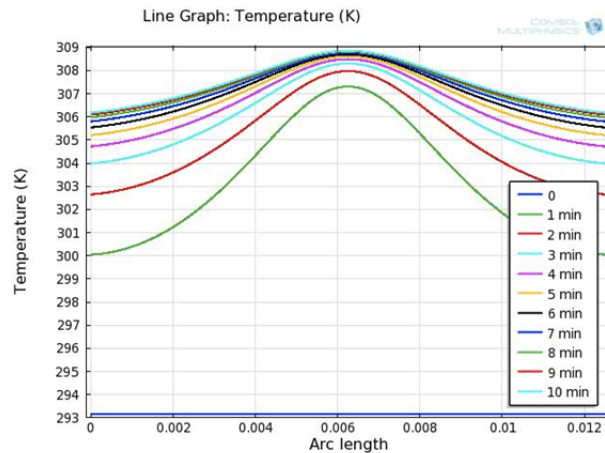


Fig. 7. Temperature distribution on the upper surface of the 3D model versus the arc length of the surface. The temperature values after 6-7 min get very close to each other, which indicate convergence to the steady-state case.

crested weir. Some students believe that the water depth will increase over the weir under sub-critical (slow and deep flow) conditions. Actually, the water depth decreases and transitions to supercritical (fast and shallow flow) conditions. The dominant explanation was that flow choking would occur as water hits the weir and backs up rather than flowing over the obstruction.

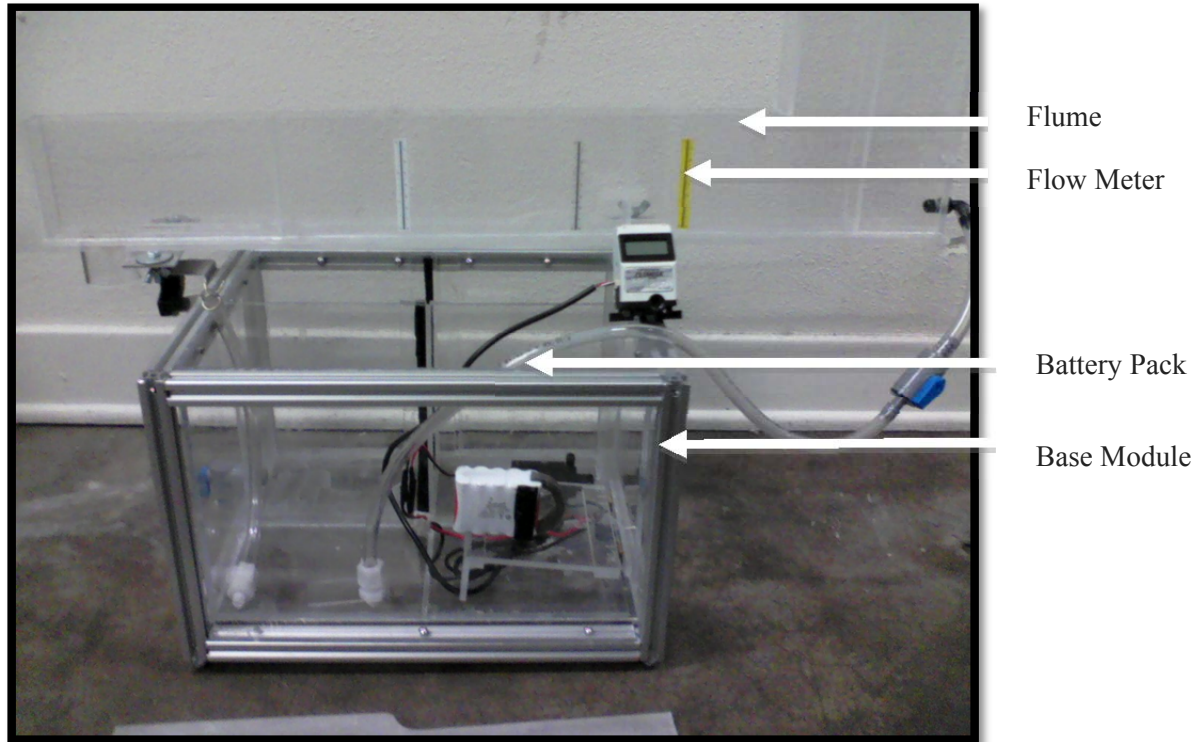


Fig. 8. Civil Engineering flume DLM in an approximate 10" x 10" x 15" reservoir with a 2" wide, 3' long flume. Water is recirculated by a submersible pump and various flow obstructions may be inserted to promote various flow regimes.

HGL/EGL

The hydraulic and energy grade lines (HGL & EGL) are a simpler concept to understand but results show that a large portion of students may carry robust misconceptions about where they are placed for an open channel flow profile. The HGL includes the elevation and pressure (depth for open channel flow) of a system, which always places it at the water surface. The most common answer from the participants was that the HGL was placed above the water surface. The EGL includes the elevation and depth like the HGL, but is separated by the energy in the system. The most common answer from participants stated the EGL is placed at the water surface. The main explanation was that there is no pressure in an open channel system and pressure is only the difference between EGL and HGL

Flow Transitions

All four types of flow transitions were given to the participants tested (supercritical drop/lift and subcritical drop/lift). The transition most commonly answered incorrectly was a supercritical drop. A supercritical drop causes a decrease in water depth due to an increase in specific energy. This is the opposite of a supercritical lift, which causes an increase in water depth after the tran-

sition. The most common misconception found suggests that some students may hold an incorrect mental model relating to flow transitions. Some students thought that water depth actually increases rather than decreases as a hydraulic jump occurs at the transition point.

Most Efficient Section

The most efficient section of a channel is a geometric shape that most resembles a semi-circle. For constructability purposes, this is most often a trapezoidal shape as that shape can convey the most amount of water for the least amount of frictional losses. Almost 75% of tested participants indicated a triangle shaped channel was the most efficient; which is incorrect.

These brief results show that a significant portion of students may hold robust misconceptions related to open channel flow. We therefore modified the original DLM and tailored it to the concepts above. We are currently implementing 15 of these DLM's replacing a lecture based teaching method with a hands on, active learning atmosphere that will hopefully correct any robust misconceptions and reinforce any correct beliefs. We also, based on preliminary results, have made three worksheets to accompany the DLM for students to work through and develop a correct working knowledge of the commonly developed misconceptions. We plan to replace three lecture days with interaction with the DLM. Each day will focus on a common misconception related to: 1) hydraulic jumps and the hydraulic and energy grade lines; 2) flow profiles; and 3) flow transitions, e.g., from subcritical to supercritical or vice versa. The same pre and post-test used in fall 2011 was administered to the class before and after exposure to the DLM. We will contrast the pre and post-tests from DLM exposure to the collected baseline data and will report a results summary at the 2012 ASEE Meeting.

An example worksheet appears below. Students are also asked to explain their answer with hopes to map their cognitive process and understand their thinking. Finally, they are asked to rank their confidence.

Example worksheet exercise:

Complete each of the channel profiles on the following pages:

State whether or not a hydraulic jump could occur.

If a hydraulic jump is possible, explain what other factors are necessary for a hydraulic jump to occur.

If a hydraulic jump is not possible, explain why.

Complete the profile by drawing the flow profile on the sketch. (i.e. draw a line representing the top of the water)

Note: Assume that flow is at steady state. This scenario begins with subcritical flow.



Is it possible for this channel profile to produce a hydraulic jump (yes/no)?

Draw the flow profile (include a hydraulic jump if you think it is possible to produce with this profile). Explain your reasoning.

How confident are you in your answer?

1	2	3	4	5
Not confident (I guessed)				Very Confident (I know I'm right)

Assessments in Other Implementations

Similar strategies to those in Civil Engineering are used in the Chemical Engineering implementation and planned for the Bioengineering implementation. For example in ChE pre- and post-quizzes are given along with exam questions to gauge long-term retention. The class is split in two with half receiving a lecture and half a hands-on experience on a topic such as a shell and tube heat exchanger. Then the two halves are switched for another topic such as an evaporative spring-coiled cooler. Assessments will be done using a rubric based on Fink's cognitive learning domains. Again, we expect to present preliminary results on this assessment at the 2012 ASEE Meeting.

New Chemical Engineering cartridges

Extended Area Heat Exchanger for Senior Lab

A group of chemical engineering students worked with a DLM during a Unit Operations Laboratory course in support of gathering accurate heat transfer coefficient data for the extended area heat exchanger cartridge (using water for the heat source, and air for the cooling medium). The DLM system (Fig. 9) consists of two reservoirs (Tanks A & B), and a pump, rotameter, gate valve, and thermocouples for inlet and outlet ports to the selected cartridge (in this case an extended area heat exchanger or EAHE) for each reservoir. Power is supplied to the pumps and thermocouples via an internal rechargeable battery.



Fig. 9. Front view of the Desktop Learning Module (DLM) with an extended area heat exchanger cartridge.

Using two different system set-ups (an unmodified DLM and a DLM re-plumbed to achieve liquid Reynolds numbers greater than 640), this group of students was able to calculate overall heat transfer coefficients for liquid Reynolds numbers ranging from 90.9 ± 19.9 to 1530 ± 140 (at a constant air speed of 1.5 m/s). Values were compared to models based on correlations (Davenport air-side, Hansen liquid-side, and Aoki air-side, Hansen liquid-side) for louvered-fin flat-tube extended area heat exchangers [33].

Preliminary results reveal some methodologies were leading to uncertain results for these EAHE cartridges during in-classroom use. In search for more accurate and precise results, thermocou-

ples were placed at the inlet and outlet for the air-side flow streams, as measurements show the inlet air temperature being greater than that of the room (due to outlet air recirculation caused by restriction of flow behind the EAHE cartridge). In addition, the total air pass area was reduced, as there were parts of the fan assembly (such as the supports) that were blocking airflow through the core. Air-side heat duties were used in the experimental calculation of the heat transfer coefficient as heat was being lost in the feed and return tubes on the water side as well as the core.

After these corrective actions were taken, new results suggest the EAHE cartridge is best modeled with the Davenport air-side, Hansen liquid-side models. Over the range of flows used, maximum and minimum deviations of 16.1 and 0.4 % from this model occur at liquid Reynolds number of 120 ± 108 and 364 ± 37 , respectively. On average, the heat transfer coefficients were lower by 40 - 45%, than those predicted using the Aoki air-side, Hansen liquid-side models which is comparable to values that were 35% lower as reported by Ng et al.[33]. These results could be because the geometry of the louvers on the fins of the air-side significantly affect the air-side heat transfer coefficient. The Aoki model only takes into account the louver pitch, while the Davenport model takes into account the pitch as well as other geometric dimensions such as the louver height, and the louver length.

Shell & Tube Heat Exchanger Design

A new shell and tube heat exchanger cartridge was designed to balance high temperature differences with high flow rates. To do this a model in MATLAB was created to solve for the maximum flow rate possible given the pressure drop through the system, then to solve for the temperature difference between the inlet and outlet on both the shell and the tube sides. Pressure drops across each component of the DLM were measured and an empirical equation was developed to use the model of the heat exchanger. The different components in the pressure drop model include the rotameters and the fittings that connect to the cartridge. Now that the model is developed one can input the initial temperatures of water in the two tanks and tube inner diameter. In the final design, seven 1/8" tubes with 0.065 in. inner diameter were determined necessary to give a minimal 3°C temperature drop, desired for system applicability, when starting with room temperature water and 40°C reservoir water. The flow rates needed for the system are determined to be 24 GPH on the tube- and 30 GPH on the shell-sides.

Boiler/Condenser

A new boiler / condenser design prototype will be used. We are considering water and fluorinated hydrocarbons as work fluid options. The fluids placed under vacuum will boil when in contact with hot tap water run from the DLM reservoir through a pipe to which the fluids are exposed. Fluid will then condense when exposed to room temperature tap water on contact with a pipe at the top of the cartridge. In the test system pressure measurements will be made to determine if vapor pressures developed are not so great as to damage the cartridge. Also, we will assess whether fluids will boil in a reasonable amount of time for classroom use.

Mechanical Engineering Solar Cartridge

Solar thermal methods are being incorporated into the undergraduate curriculum at Embry Riddle Aeronautical University (ERAU). Textbooks that include solar thermal approaches are used but we still lack ideal hardware to demonstrate clearly solar thermal power collection. The solar powered Organic Rankine Cycle DLM cartridge being developed at ERAU will enhance engineering education in the thermal sciences first, because it is a desktop scale steam power plant and second, because it will be driven entirely by heat from the sun. Currently, a solar powered boiler has been designed and tested that, by itself, enhances a heat transfer lab by demonstrating all three heat transfer modes: radiation, conduction, and convection. The box encompassing the sun, concentrator, and boiler in Fig. 10 indicates the current tested components of the Organic Rankine Cycle DLM cartridge.

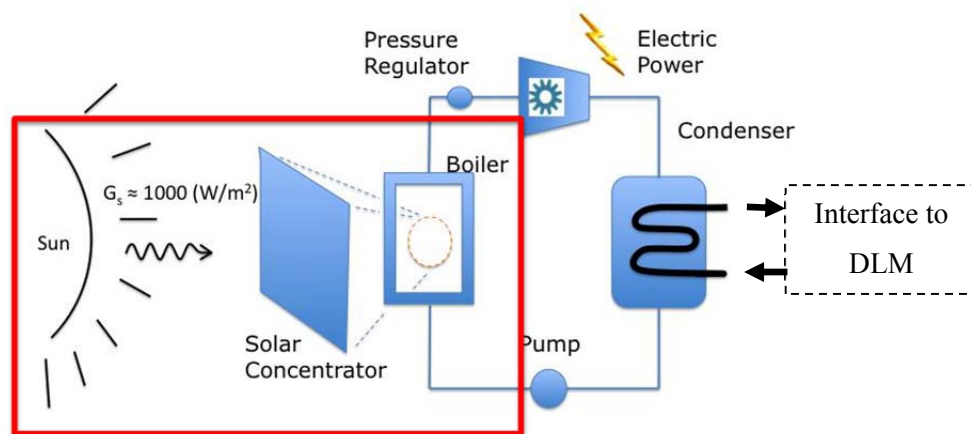


Fig. 10. The solar powered boiler subsystem was designed and tested. The complete Organic Rankine Cycle will interface to the Desktop Learning Module (DLM) through the condenser's cooling water.

The planned interfaces to the Organic Rankine Cycle are through the condenser's cooling water circuit, boiler temperature and pressure measurement, and electric power generation measurement. The complete Organic Rankine Cycle is an ongoing effort. Fig. 11 shows a schematic of a newly designed and validated boiling chamber, which is then enclosed by glass, that generates steam entirely from the sun in 4 - 5 min. Using a solar concentrator, the sun's heat is focused onto a copper absorber plate that then acts as a heating element. The absorber plate is surrounded by water and receives solar power via radiation through high temperature glass. The energized copper plate heats the working fluid through convection. The hot side is painted black to increase absorptivity. This is a direct steam generation boiler so the entering water stratifies upon boiling into two steady-state flow regions with both liquid and gaseous phases. High temperature glass on both sides with rubber gaskets holds the water and steam inside the chamber and passes the solar radiation to the heating element. The opposite side's glass allows students to clearly observe the continuous two-phase stratified flow. The boiler's aluminum body has milled channels along the side and top chamber walls to provide insulating air pockets that hinder heat loss from the boiling chamber to the surroundings.

Test results are positive and students clearly see the steady state boiling and exiting steam. It is clear that the boiling condition has resulted entirely from concentrated solar power. An RTD temperature sensor measures water temperature on the side opposite the solar hot spot to avoid solar radiation causing artificially high temperatures. The temperature rises to and remains at 100°C corresponding to boiling water and students can see steam exit the boiler within 4-5 min. Fig. 12 shows three images in a sequence of increasingly rapid boiling conditions.

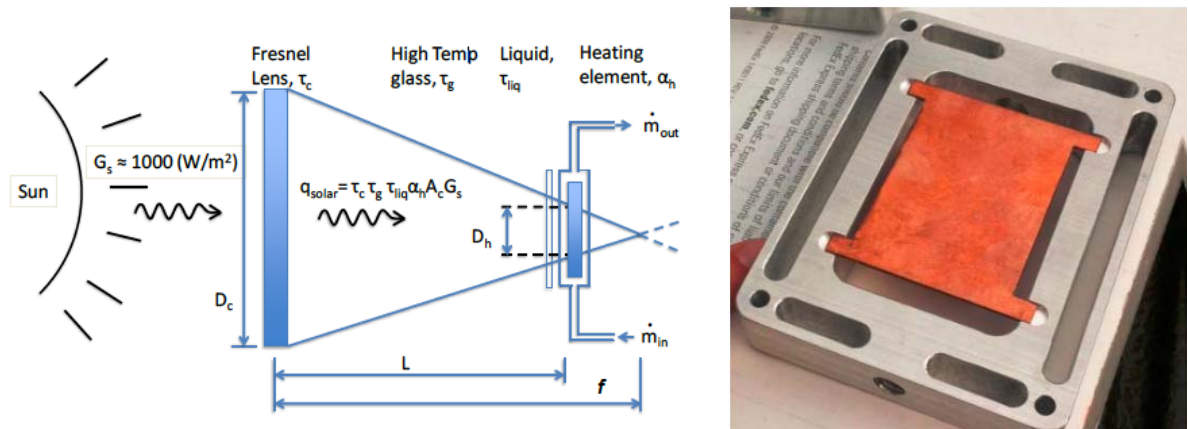


Fig. 11. A 0.9 m diameter Fresnel lens focuses approximately 1m^2 of solar heat onto a copper heating element. Under ideal solar conditions the Fresnel lens concentrates 1kW of solar thermal heat onto a 3 cm diameter hot spot. Water enters the boiler's inlet on the bottom and exits as steam from the top.



Fig. 12. Boiling process. As boiling becomes more rapid students see progressively larger steam bubbles form on the copper plate. From right to left, these views show low, medium, and rapid boiling conditions. The photos are taken from the back, opposite the solar hot spot that transfers heat to the copper heating element via radiation. The heating element distributes and transfers heat to the water through conduction and convection.

The boiler dynamically illustrates radiation, conduction, and convection. A laboratory lesson has been developed for estimating the steam's volumetric flow rate from water inlet measurements. Students also estimate solar-to-steam power efficiency. Initial measurements showed solar power conversion of 27%. The next steps are to mount a small Pelton wheel turbine to the boiler's exit and close the Rankine Cycle loop with a condenser and pump.

Conclusions

Collectively our team has set out to create a larger set of new miniaturized, yet rigorous, hands-on learning cartridges that snap-in to the DLM base unit. These not only include miniature process industry equipment, but also miniaturized civil engineering structures i.e. weirs, and systems for studying biomedical and bioengineering principles. All show promise, yet need further development. A rigorous pre- / post- assessment strategy has been developed based on extensive interviews with students that revealed misconceptions in civil engineering hydrodynamics. A similar implementation is being used in Chemical Engineering based on previous implementations of similar pedagogy. This tact is also planned for use in the Bioengineering courses. Assessments will be used to collect baseline results for a lecture-based course. Plans for assessment implementation along with the hands-on DLM intervention are underway and initial results will be presented at the 2012 ASEE Meeting.

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